FINAL TECHNICAL REPORT

Award # 06HQGR0038

GEOTECHNICAL ARRAY DATA ANALYSIS AT THE ANSS ANCHORAGE SITE AND NEES/ANSS INTEGRATION

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ABSTRACT:

A significant component of the research efforts at the Institute for crustal studies (ICS) are centered around understanding the physics of the earthquake process and the effects of earthquakes on the built environment. These require not only computational facilities for doing theoretical modeling of wave propagation and earthquake source process simulation, but also field observatories for monitoring earthquake activity. These field observatories provide the control data for testing our theoretical models and simulation techniques, so we can determine if our models are matching real observations of earthquakes. One of these field observatories is the Delaney Park Array (DPK), located in downtown Anchorage, AK (Figure 1). This observatory was installed with joint funding from the ANSS program and the National Science Foundation (NSF). The site is now integrated into the NSF George E. Brown Jr. Network for Earthquake Engineering Simulation (NEES) program, through the multi-agency collaboration with the US Geological Survey, facilitated by this NEHRP external program award.

Figure 1. Map showing the location of the Delaney Park Geotechnical Array.

In June of 2007 through funding under this USGS program, the DPK site was upgraded with a Kinemetrics, Inc. Marmot field processor that allowed the site to be integrated into the NEES@UCSB data acquisition and processing infrastructure. Continuous data from the DPK site now flows in real-time to UCSB and is archived. In addition, routine processing which segments out events from the continuous data stream for the NEES field sites is also now set up for the DPK station. Automated data analysis of each event waveform provides peak acceleration, peak velocity, and signal to noise ratios for each record. Through the NEES@UCSB program, we have also been developing web-based applications for state-of-health monitoring and data dissemination tools for all the instrumented geotechnical field sites. The DPK site has now been integrated into these online processing and analysis tools.

Background: The Delaney Park Geotechnical Array

Downtown Anchorage Alaska sits on top of the great Alaskan subduction zone and has been subjected to large damaging earthquakes in the past. The March 27th, 1964 (Good Friday), magnitude 9.2 great Alaska earthquake shook the ground for more than 4 minutes over a 50,000-square-mile region, caused 131 deaths and significant damage. Figure 1 shows a Google map of the Anchorage area with the Anchorage city skyline (inset top) and the recently instrumented Robert Atwood building as seen from Delaney Park (inset right), the site of the ANSS geotechnical array (inset left).

Instrumented buildings are a significant component of the USGS Advanced National Seismic System(ANSS). In order to examine structural response as well as soil-structure interaction, and the effects of surface geology on the input motions to structural arrays, the ANSS program has deployed borehole instrumentation at some instrumented structures in the United States. The Delaney Park Array, deployed to provide the input wavefield to the instrumented Atwood building, has 3-component accelerometers at 6 levels (Figure 2) within the near-surface soil column and also at the surface.

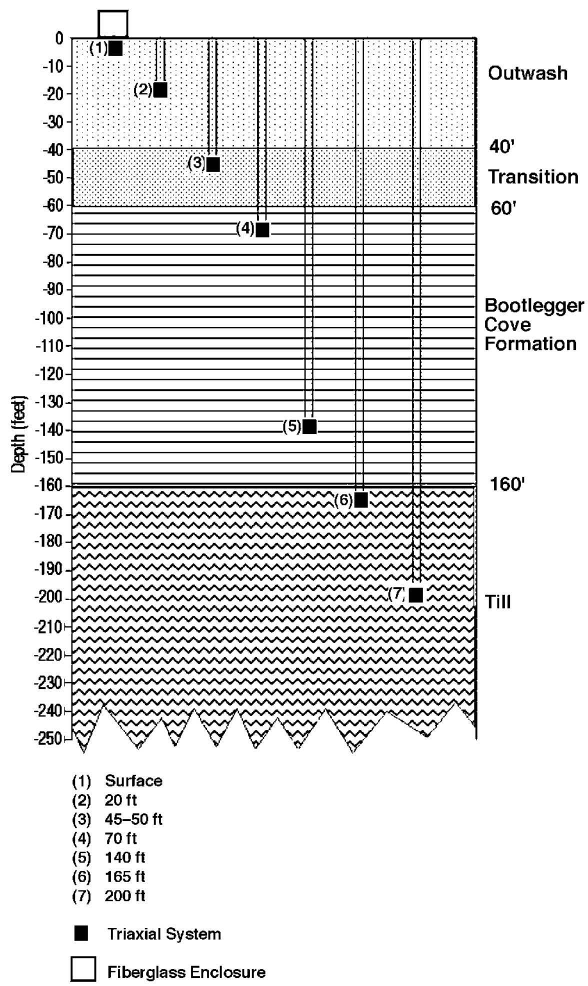

Figure 2. Schematic of the soil profile and geotechnical array layout at the Delaney Park Array in downtown Anchorage, Alaska.

A soft formation called the Bootlegger Cove, is thought to be responsible for much of the damage in anchorage during the great 1964 earthquake. Blow counts are down in the single digits at depths of over 100 feet in this formation and wave velocity decreases with depth through this formation (Figure 3). The geotechnical array is deployed to both sample the ground motions within this formation and above and below it.

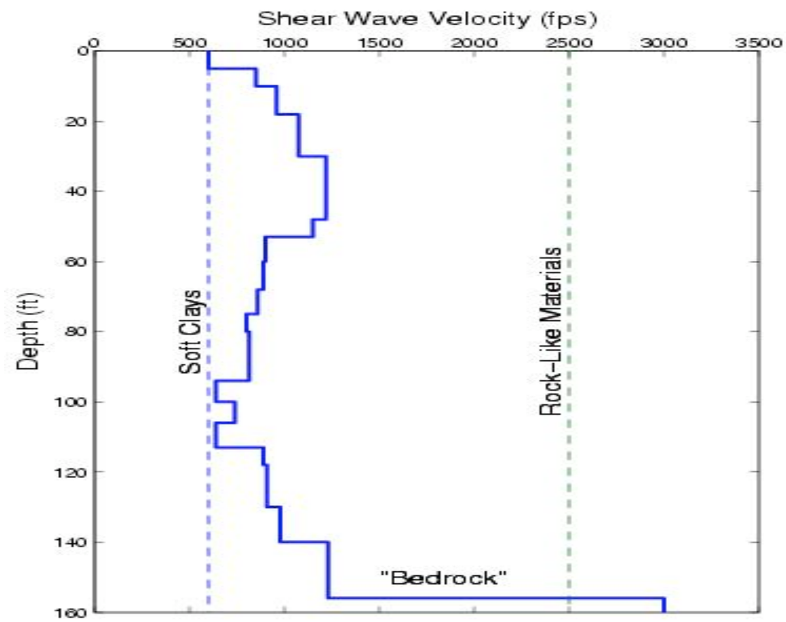

Figure 3. Estimated shear wave velocity with depth in downtown Anchorage.

The instrumentation consists of six Kinemetrics 3-component downhole FBA ES-DH (*Hyposensor*), and one surface FBA ES-T (*Episensor*). Data is acquired on four Quanterra Q330 6-channel data loggers that are installed inside a surface enclosure (Photo 2). The sensors are configured for +/- 4g ground motions, with a differential 5 Volt/g sensitivity set to exactly match the differential input on the Q330 datalogger. The site is equipped with large capacity batteries that power the sensors and data acquisition systems. AC power is installed at the site with charge controllers keeping the batteries charged. In the event of a power outage the site could operate for more than two weeks before the batteries would need to be swapped out. Since the site is located in downtown Anchorage, AC power should hopefully be restored before the batteries need replacing.
The site is connected to the Internet using a DSL telemetry link and data flows to UCSB and then to a number of other organizations, including USGS Menlo Park, and the University of Alaska, Fairbanks. The telemetry link easily supports the real-time continuous data streaming of 18 channels at 200 samples per second. Currently the data loggers are also each connected directly to a Kinemetrics *Packet Baler* that serves as a deep storage backup (20 Gb hard drives which can hold over a year of data) in the event of a prolonged telemetry outage.

A typical example of the quality of data being recorded from this array is shown in Figure 4. These are the north-south component recordings of a magnitude 3.3 located with ~60km of the city at 32 km depth that occurred in February of 2008. The top trace in Figure 4 represents the ground level sensor, and the bottom trace is the deepest sensor at 60 meters depth, in the competent material below the bootlegger cove formation. The 4th and 5th trace from the top are recording within the Bootlegger Cove formation. The scale is the same on all traces, with the max values at ~ +/- 0.1%g or 1.5 cm/s^2. The signal to noise level is typically good for events that produce 0.1%g or better. We have segmented out 100's of events within 150 km of the Delaney Park Array from the real-time continuous data stream, but since most of these are at depths of 30-50km or more, it's primarily the M2.5 to M3.0 events that have good signal to noise and this depends on the depth of the event.

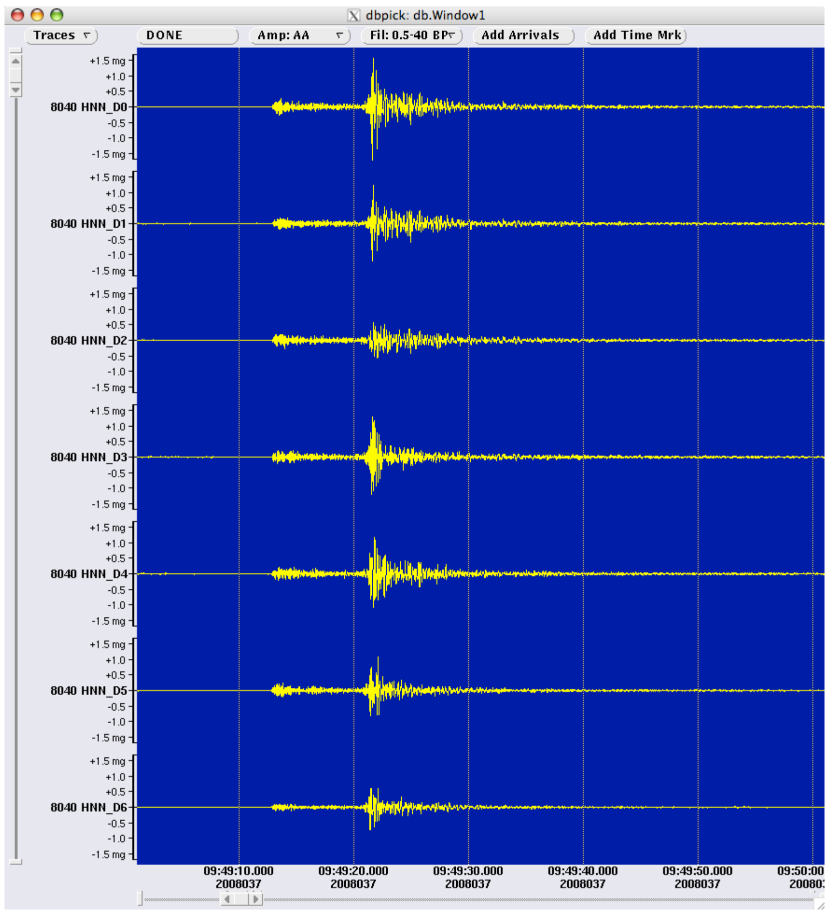

Figure 4. Acceleration waveforms of a M3.3 earthquake recorded at the Delaney Park Geotechnical Array in February 2008.

Project Deliverables and Results:

A primary focus of this project was to upgrade the DPK field site and integrate it into the acquisition, processing, analysis, and data dissemination tools that are part of the NEES permanently instrumented field site program at UCSB. The upgrade included the deployment of a Kinemetrics Marmot field processor, running Linux and the Antelope software that enables the local buffering of continuous data, and simplifies the real-time streaming of data back to UCSB. Figure 6 shows the installed Marmot field processor at the DPK site.

Figure 5. Instrumentation hut at DPK with Marmot field processor in the back right corner of the hut. Surface accelerometer can be seen in the forground.

The addition of the Marmot field processor at DPK allows for buffering of about 9 days of continuous data on solid-state flash. Any telemetry outage less than 9 days is automatically recovered from with no human intervention as part of the normal operations using the Antelope software package. In addition to the buffer provided by the Marmot, the packet baler systems connected to each Q330 datalogger have the capacity to hold over a full year of continuous data.

One advantage to having real-rime communications and data delivery is the ability to monitor the state of health of data acquisition equipment at the site, and the functionality of the sensors. Data processing developments made possible through the NEES@UCSB program provide web-based access to state-of-health information about each of the permanently instrumented field sites. Figure 6 is an example of the temperature, power supply voltage, and current usage at the DPK site for a 1-month period as recorded by the data acquisition system.

This web-based interface allows users to access information at a variety of time scales including hourly, daily, weekly, monthly, yearly, or lifetime of the station. The temperature environment in the enclosed fiberglass hut (see Figure 5) can produce extreme cold temperatures in winter when it's covered by snow, and the opposite extreme in summer when there is no way for the heat generated by the equipment in the hut to escape. Daily variations in temperature can be more than 30°C as can be seen in Figure 6 and extremes can range from -20°C to +50°C depending on the season.

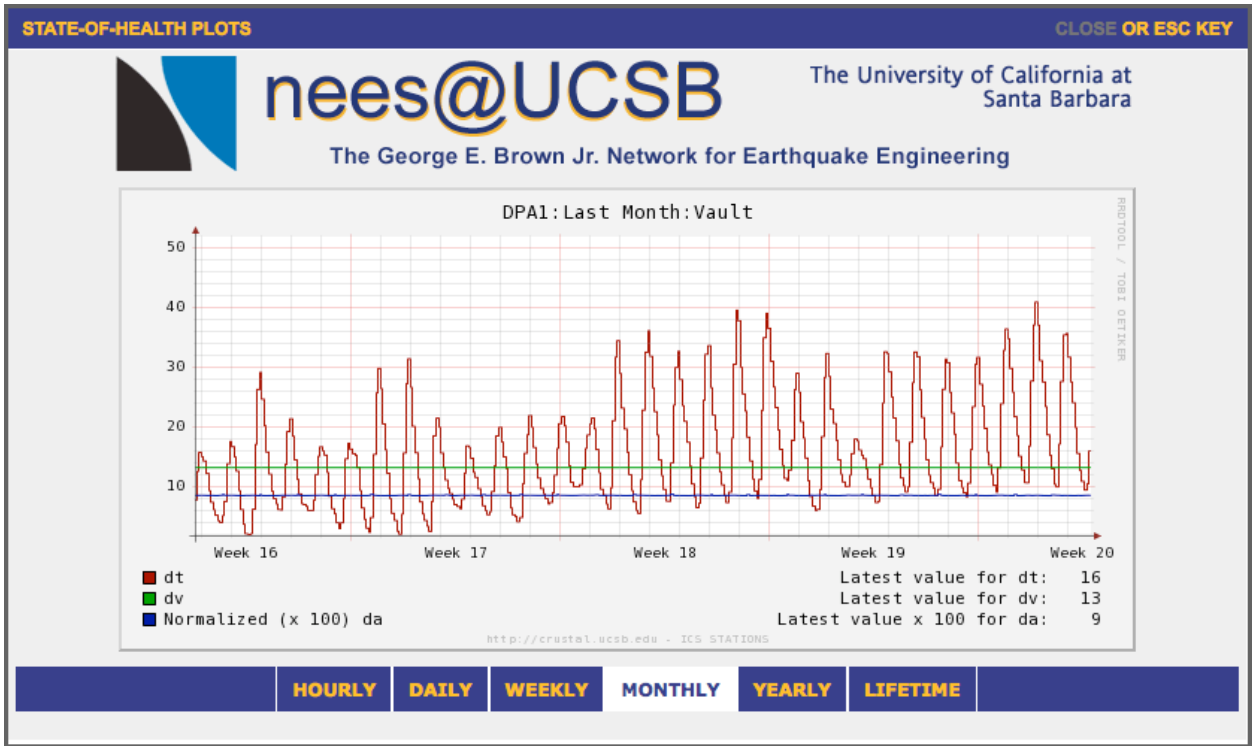

Figure 6. Screenshot showing the incorporation of the DPK site into the NEES@UCSB web-based site monitoring tools. Station state-of-health parameters such as power and temperature are provided through a web-accessible interface. [http://nees.ucsb.edu/facilities/dlmon]

The ability to observe waveforms from any of the sensors in real-time provides us with a constant functionality check on the status of the sensors. A real-time 24-hour display of all sensor channels back at UCSB lets us quickly know if there are problems with a datalogger, sensor, or individual component.

The routine processing and analysis of data from the NEES@UCSB field sites includes the segmenting out the earthquake waveforms from the continuous data using a distance scale based on magnitude range. Small events are segmented out only when they occur close to the site, as the events get further from the site, a larger magnitude is required before the event will qualify to be segmented out of the continuous database. We use the ANSS catalog of earthquakes (which includes regional network determined magnitudes and locations) in this process of creating the segmented event waveform database. The DPK site is now included in this routine data processing that was developed under the NEES program. The data shown in Figure 4 is one of these segmented events.

In addition to the automated segmenting of data from the DPK site, earthquake waveforms are examined periodically to ensure functionality of the sensors. The event data is stored in an online database at UCSB using a RAID storage system that allows for instant access to these records.

One of the goals of the NEES@UCSB facility is to improve data dissemination from geotechnical array sites. Over the last few years, a web-based dissemination tool has been developed to help increase the number of researchers using this data. The idea is to make the segmented event database searchable, and the waveforms accessible, via an online data portal. This process is now almost completed, though development continues as we get feedback from users. The DPK data has been integrated into this data dissemination tool as shown in Figure 7.

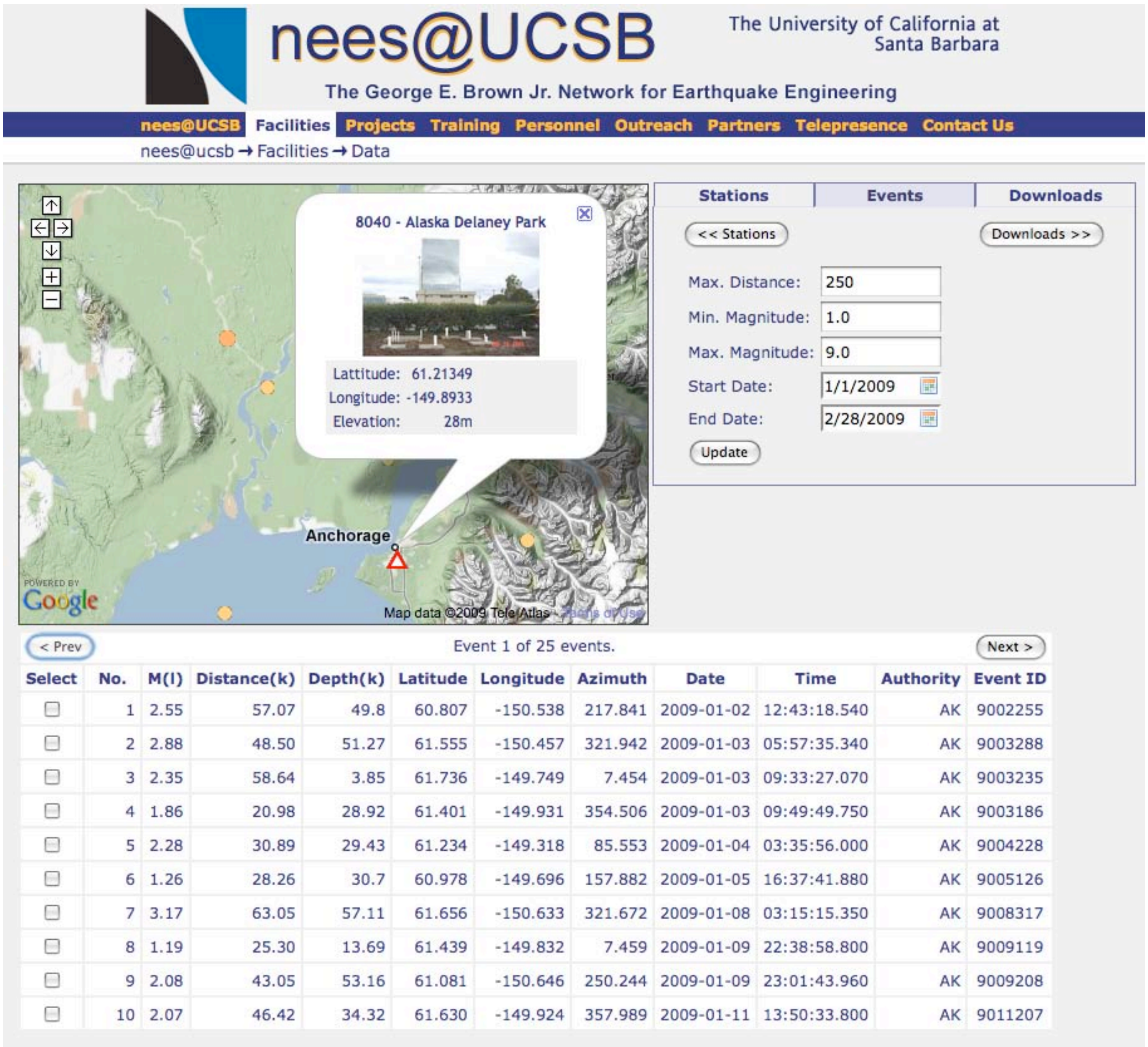

Figure 8. Screenshot showing the incorporation of the DPK site into the NEES@UCSB web-based data dissemination tools.

From the NEES@UCSB website, the search interface currently provides the ability to select a station from a Google Map interface or drop down menu. The available channels are then shown for the particular station, with the ability to select individual channels, or all channels. The Event tab will then provide the ability to search for available events based on magnitude, distance, and time period. The event search returns a list of events with the events also shown on the Google Map interface (Figure 7). After selecting the event, the user can then download individual waveform files, or package a group of files, with the ability to continue to add packages for other events, before downloading all selected packages.

Currently, data is provided in three formats, miniSEED, ASCII (for Excel or MATLAB), and RDV (a variation of ASCII that is meant for the NEES Java based real-time data viewer tool). The miniSEED format is provided in raw counts and is for more advanced users. The ASCII data formats can be provided with calibration applied to physical units, or in raw units by the user. Making other data formats available for dissemination, for example SAC, is under consideration and will depend on user feedback. Tracking mechanisms for the number of waveforms downloaded and the number of users will also be available. Search capabilities using signal-to-noise ratios, peak acceleration, and peak velocity are currently under development. Lastly, the ability to view waveforms and zoom in and out through the web browser is currently under development in a collaboration between the EarthScope Array Network Facility and the NEES program. This web-based waveform viewer should be available in summer 2009. The DPK data will be incorporated into these developments.

Conclusions and Future Work:

The project has been successful from the standpoint of the integration of the DPK field site with the NEES program. The primary goal of installing the Marmot field processor and establishing a link to the automated processing tools developed under the NEES program has been accomplished. Beyond this, the data dissemination tools and all other future NEES software development work will also be directly applicable to the DPK field site. Future work is planned to integrate the DPK event waveform database into the MATLAB analysis tools currently under development. This will provide the ability to easily access the event waveform database and perform vertical array seismogram inversions to examine attenuation and site response analysis in the low-strain regime, and eventually the large-strain regime when the Earth decides to cooperate.

Publications:

The general data dissemination tool development has been reported at the 14th World Conference on Earthquake Engineering, and while the DPK site was not specifically mentioned in this publication, the development tools apply to DPK as well as the other NEES and non-NEES sites.

Steidl, J. H., R. L. Nigbor, T. L. Youd (2008). Observations of *insitu* soil behavior and soil-foundation-structure interaction at the George E. Brown, Jr. network for earthquake engineering simulation (NEES) permanently instrumented field sites, *Proceedings of the 14th World Conference on Earthquake Engineering, October 12-17, 2008 Beijing, China*, paper S16-01-014.

Once the web-based waveform viewer and event search tools are completed, we plan to submit a Seismological Research Letters manuscript to help publicize the data availability and web-based dissemination tools.

The waveform analysis and seismogram inversion results are still a work in progress. We have been porting the inversion code over to MATLAB so that we can take advantage of the Antelope waveform database interface to MATLAB. This will allow easier and more automated processing and analysis of events. A research study is in progress related to the site response and attenuation effects at the DPK site, as well as other geotechnical array sites, and this will result in a publication in either Soil Dynamics and Earthquake Engineering or the Bulletin of the Seismological Society of America. Funding under this program will be acknowledged when this paper is published, and a copy will be provided.